

# Feynman Clocks, Causal Networks, and the Origin of Hierarchical 'Arrows of Time' in Complex Systems. Part I. 'Conjectures'

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## Abstract

A theory of **time** as **information** is *outlined* using new tools such as **Feynman Clocks (FC)**, **Collective Excitation Networks (CENs)**, and **Sequential Excitation Networks (SENs)**.

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## 1 Introduction

*Should we be prepared to see some day a new structure for the foundations of physics that does away with time?... Yes, because "time" is in trouble.-John Wheeler [1].*

*'Physical time' will emerge as a sort of secondary collective variable in the network, i.e. being different from the clock time (while being of course functionally related to it)- Manfred Requardt [2].*

It has been suggested by Julian Barbour that 'time' does not exist [3]. It is the position of this author that 'time' is in fact does 'exist' and is a different 'property' of evolving systems than has been previously assumed.

Conventional 'time' is *functionally related* to the *signals created by re-configuration or 'decoherence'*[4] *transitions between the physical states of clocks*. These signals are *detected* by the conversion of a signal into an excited state in a detector. This process produces *state information* (e.g. *configuration* observables such as energy) in the detector connecting it to the source and its signal on an 'arc' between two nodes of a *causal network*.

The detector states can be sequentially 'clocked' into ordered memory registers through a process of '**signal mapping**'. The state information stored in these registers can be used to create a 'time dimension' by *mapping* the ordered set of memory states onto the real number line. *Information processing systems* (e.g. quantum computer 'gates', neurons, the brain etc.) are an integral part of the creation of 'time' as a measure of the difference between configurations of a system with respect to a 'standard clock'.

Much of the confusion about the *nature of time* is connected with the *spatialization* of 'time'. The use of 'shift' vectors and 'lapse' functions [5] takes 'explicit' clock time and masks it in an implicit form of 'distance' between 'universal state configurations'. These are specified by the distribution of matter and energy in 'space' (vacuum).

The 'problem of time' is primarily about the emergence of macroscopic irreversibility (e.g. entropy) from reversible microscopic symmetries (the ' $T$ ' of CPT invariance). The *quantum arrow of time* is defined by the *irreversible* 'decay of a discrete state resonantly coupled to a continuum of final states' [6] observed in various nuclear and atomic processes. We will see that apparent 'time' reversibility and irreversibility are compatible and necessary aspects of quantum systems. The '*Program of Decoherence*', the entanglement of quantum states, and the emergence and decay of novel collective excitations provide tools [7], [8], [9] for understanding the common roots of all arrows of time for unstable configurations of hierarchically scaled clusters of matter in an evolving universe. This scaling leads to 'classical' or macroscopic aspects of reality that are in fact special cases of a 'quantum universe' [10].

We begin with the premise that **time is a number created by the processing of information**. Scalar division of this information by Planck's constant creates a real number with units of 'time' (seconds). The information (in this context has units of 'energy') is propagated by **signals** between **Feynman Clocks (FCs)** to **Feynman Detectors (FDs)**. The FD is the signal absorption mode of the FC and unless indicated, 'FC' will be used to represent these two modes of a single system. The conversion of this state information into numbers provides the basis for building the 'time dimension' of space-time by measurement of the differences between two numbers. The creation of these numbers from the detection events is accompanied by the loss of information about the states of the signals and clocks. The increase in information entropy will be important in understanding the 'lifetimes' of local and distributed information structures in quantum computation.

The **special theory of time** describes how the fundamental quantum mechanisms involved in the reconfigurations of unstable systems generate information states defining an irreversible 'quantum arrows of time'. The **general theory of time** describes how the quantum arrow of time can be used to define macroscopic arrows of time associated with transfer of state information in complex systems and causal networks [11]. It is the author's position that unified or comprehensive 'theories of everything, everywhere, at anytime' require a *deep* understanding of 'time'. Conventional ideas of 'time' have been the implicit and explicit source of many contradictions and paradoxes in physical theories.

The purpose of this paper is to examine the premise that all temporal processes in macroscopic complex systems can be understood as being generated by a microscopic **irreversible quantum arrow of time**. The *correspondence* between the various separate biological, cosmological, psychological, radiative, and thermodynamic '*arrows of time*' [12], [13], [14], [15]

is achieved with *causal networks* built up hierarchically from the quantum arrow of time. *Preliminary* and *speculative* ideas and tools are presented in order to see if a 'deeper' descriptive and computational 'language' of 'time' as 'information' is possible.

## 2 An Approach to 'Time'

The description of 'time' explored in this paper is built on the following conjectures:

**Conjecture 1** *'Time' is a form of 'information'.*

**Conjecture 2** *Information is created by reconfigurations of unstable states of systems.*

**Conjecture 3** *Reconfigurations of systems produce or process 'signals'.*

**Conjecture 4** *Signals connect clocks to detectors. A Feynman Clock (FC) or 'gate' is a generalization of a quantum clock [16] with multiple signal input and output 'processing' capabilities. Signals are essential for the creation of causal networks. Signals are 'quantum' in nature but may appear 'classical' as a result of their collective scale, statistical entanglement, or intensity. They may be identified with a transition in a macroscopic Plateau of Complexity or 'POC' (see below).*

**Conjecture 5** *The Quantum Arrow of Time (QAT) is a pointer. It is a function mapping the irreversible transition from an excited or unstable configuration to a coupled 'stable' one in a FC system. The 'direction' and 'magnitude' of these 'arrows' are specific to the quantum system being observed. The general QAT is really a statement about unstable states of system coupled to one or more states from within a set of all possible reconfigurations of that system. These pointers are 'information vectors' in an 'information space' [17]. The state information transfer between clocks and detectors by the signals can be mapped by these vectors in the information space. All QATs for various localized systems in the current universe are 'traceable' back to the fundamental QAT mapping the decoherence and decay of the initial excited state of a FC-Universe at the beginning of the Big Bang.*

**Conjecture 6** *The **creation** of an **unstable state** in a system by the **detection** of one or more simultaneous or staggered **signals** is the '**detector**' mode of a clock.*

**Conjecture 7** *The '**decay**' or '**decoherence**' of this state with the emission of one or more **signals** is the '**clock**' mode of the system.*

**Remark 1** *Note that the term '**clock**' or **FC** will be used to represent any system that has **both** detector and clock modes unless otherwise noted. A **Feynman Detector (FD)** is the **input** or **detection mode** of a Feynman Clock.*

**Conjecture 8** ***Causal Networks** are **built** from locally **connected** sets of clock (and detector) **nodes**. These networks map the sequential progression of information or signal flow from node to node. They may also act as '**temporal interferometers**' acting on or creating **entangled signal** states [18].*

**Conjecture 9** *Causal networks of signal linked FCs processing signals **sequentially** are **Sequential Excitation Networks (SENs)**. These systems treat the signals between nodes as distinct '**classical**' objects which are decoupled from the clocks and detectors along their trajectories. We will see that the distinction between quantum and classical objects is conceptually artificial. It arises when systems exhibit collective properties that can be described without direct reference to the complex quantum causal networks underlying them. '**Classical**' methods are clearly appropriate for the application of classical physics and engineering principles in macroscopic systems where their possible disruption by underlying quantum CEs is negligible. .*

**Conjecture 10** *FCs can be "**synchronized**" by **entangled** signals by generalizing the "**Quantum Clock Synchronization Scheme**" [18]. The FCs may be separated by '**classical**' distances but act as a single quantum system. The spatial '**distance**' between two coupled or entangled nodes is a '**weak**' measure of the quantum or classical nature of the combined system. The '**distance**' which distinguishes the two nodes may be more properly '**measured**' by their **degree of entanglement** [19].*

**Conjecture 11** *Collective Excitations (CEs) (e.g. phonons) of **synchronized** sets of Feynman clocks in causal networks result from reconfigurations of excited state of the whole system. These CEs occur as novel behaviors of these **Collective Excitation Networks (CENs)**.*

**Conjecture 12** *Plateaus of Complexity (POCs) are the **physical states** of complex systems (CENs) that support **CEs** and the **collective signals** that are detected and emitted by the collective state of the components acting together as a single 'clock'. Signals are essential for the creation of causal networks. Signals are always quantum in nature but may appear classical as a result of the identification with a macroscopic POC.*

**Remark 2** *These CEs are perturbations of POC  $n$ -body states. They may be multipole oscillations of nuclei shifted energetically away from the mean POC energy states associated with 'stable' configurations. These stable nuclei occur at "**magic**" total nucleon numbers given by the proton and neutron sum  $A$ , where  $A = 2, 8, 20, 28, 50, 82, \text{ or } 126$  calculated using the 'Shell Model' of nuclear structure[20].*

**Conjecture 13** *The **spatial direction** of the **flow of information** via signals in networks defines '**arrows of time**' specific to the **signals** and their **information content**.*

**Conjecture 14** *The emergence and decay of **CEs** in **POCs** generate signals that can be used to create **hierarchical 'arrows of time'** associated with a system at a given level of complexity.*

**Conjecture 15** *Complex systems **composed** of other complex systems can generate **POCs within POCs**. POCs can act as **clocks** forming **networks of POCs** which in turn can support new CEs. This '**nesting**' of clocks and signals provides the basis for scaling from quantum clocks to neural networks. The signals between such systems that are not acting collectively form hierarchical **SENs**.*

**Conjecture 16** *All '**arrows of time**' defined for various POCs are **traceable** back to fundamental QATs.*

**Conjecture 17** *The 'direction' and 'dimension' of 'arrows of time' are created through a process of **Signal Mapping** in which the detection of non-simultaneous signals is **causally ordered** in a **memory register** by **coupling** the detector states to signals generated by an **internal** or **standard clock** [15]. The set of ordered states can then be transformed by a computer (e.g. neural network) to the set real numbers for the construction of a 'timeline'. This timeline can then be converted into the spatialized 'time' parameter of relativistic 'space-time'.*

**Conjecture 18** ***QATs are irreversible** since they are defined as originating from unstable configurations.*

**Conjecture 19** *'Time' or more properly **Configuration State Information** is **reversible** or **restorable** [15] only if an unstable state of a system can be recreated by work (injection of the wave-function information specific to the desired state) done on the system by an external 'agent'(signal). This work may be done as a quantum computation on **reconfiguration signals** by the **FD 'gates'**. This can create a **local** 'reversal of entropy' leading to an **excited** configuration of matter with the same properties as the atemporal 'previous' state of the system. The creation or re-creation of an unstable state of a system requires input information from the systems environment and is not associated with an internal QAT but with the signals QAT..*

### 3 The Quantum Arrow of Time (QAT)

The decay of *ensembles* of identical radioactive nuclei can be described in the 'bulk' or statistical perspective with the '**exponential decay law**' [21]. We will see that the system as a whole can be thought of as decaying from the initial collective excitation of a 'network' of acausal but 'connected' set of quantum systems. The 'decay law' in the ensemble paradigm is;

$$N_\tau = N_0 e^{-k\tau} \quad (1)$$

where  $N_0$  is the number of identical radioactive 'clocks' that we start with,  $k$  is the 'decay constant' specific to the type of clock and represents the magnitude of the 'instability' of the system,  $\tau$  is the 'elapsed time' for the transition from an *initial system configuration state* of  $N_0$  clocks to a *reconfigured state* of the system where  $N_\tau$  clocks remain at 'time'  $\tau$ . Since

the unstable nuclei of this system are quantum clocks, we can view this equation as the recipe for a 'collective' or 'statistical' clock built from an ensemble of quantum clocks. Solving for 'time' we have;

$$\tau_{edl} = \frac{1}{k} \left( \ln \frac{N_0}{N_\tau} \right) \quad (2)$$

which can be thought of as the *transformation* of '*reconfiguration information*' on the right into the '**lifetime**' of the transition from the unstable state of the initial system to a 'more stable' state with  $N_\tau$  clocks. The 'detection' of the  $N_\tau$  'signal' results in a real number created by the *dimensional conversion* factor  $k^{-1}$ . This number is interpreted as an 'event time' for the state of a statistical clock built from many quantum clocks.

First we observe that the decays of radioactive nuclei, excited electronic states of atoms through 'autoionization' (emitting a 'free' electron) or photon emission are described with '**time-independent**' perturbation theory;

"For example, a system, initially in a discrete state, can split, under the effect of an internal coupling (described, consequently, by a time-independent Hamiltonian  $W$ ), into two distinct parts whose energies (kinetic in the case of material particles and electromagnetic in the case of photons) can have, theoretically, any value; this gives the set of final states a continuous nature...We can also cite the *spontaneous emission* of a photon by an excited atomic (or nuclear) state: the interaction of the atom with the quantized electromagnetic field couples the discrete initial state (the excited atom in the absence of photons) with a continuum of final states (the atom in a lower state in the presence of a photon of arbitrary direction, polarization and energy)." [6]

These decay modes are not restricted to atoms and nuclei. We will see that these *quantum clocks* are *time-independent irreversible systems* that can be created in space by *apparently* 'time' reversible particle collisions. *The key to the irreversibility in quantum systems is the creation of an **unstable** configuration of matter and energy in space.* This is the '*first cause*' for decay. The decay of an unstable state creates a 'local' arrow of time pointing to more stable states for the system. *Instability* is a measure of the *geometric asymmetry* of the mass-energy distribution of the 'components' as they are driven to 'more stable' configurations by the fundamental interactions (forces) between each other.



The apparent 'reversibility' of clocks or any other complex system is an phenomena created by the interaction of spatially distinct signals and detectors. Reversibility is a collective property of a composite system formed with 'free' signals, the vacuum, and quantum detectors and clocks. 'Entropy' is a convenient mapping tool or system pointer indicating the direction of evolution of the total system while preserving the reversibility of detectors and the irreversibility of clocks.

## 4 Collective Excitations

The key to hierarchical systems of quantum systems acting as 'classical' objects is the concept of **collective excitations (CEs)** of **quasiparticles** (also called 'elementary excitations') [22], [23], [20]. **Phonons**, **excitons**, and **plasmons** are examples of CEs that exhibit mesoscopic system behaviors but are still quantum phenomena [24], [25]. Superconductivity represents an important quantum macroscopic behavior in the CE model.

If spatially extended quantum CEs can be shown to exist in complex 'classical' systems, then CE emergence and decay can define the 'lifetime' of the reconfiguration process involved with transitions between specific states. Collective excitations represent new properties of  $n$ -body aggregates of matter that are not a mere sum of the individual properties of the individual components. The emergence of these novel behaviors creates the opportunity for new 'signals' to be emitted and absorbed as resonances of the new energy eigenstates. The state information transported by these signals is also new. These signals allow identification of the transitions between states in the spectrum of CE states of a complex system. These phonon or phonon-like signals can link other CE systems in hierarchical causal networks.

Recent work on the synchronization of quantum clocks provides a model for CEs as entangled states in widely separated systems through a "*quantum clock synchronization scheme*" [18]. This model can be expanded for Feynman Clock Synchronization over 'classical' distances where the FCs are virtual clocks (entangled 'time' independent *signals*) until 'measured' or decohered from an atemporal global CE state into 'actual' FC states of the nodes in a causal network. These synchronized nodes create a CEN without the exchange of 'timing information'. Evidence of CEs over great distances is found in photon entanglement experiments.

Experimental observation of two 'energy-time' entangled photons separated by more than 10 Kilometers [26] provides an example of the *decay of a collective excitation* of a vary large spatially extensive quantum sys-

tem *if* we look at the entire experimental setup as a 'SEN' system from the 'Geneva FC' to the Bellevue/Bernex 'CEN'. The 'Geneva FC' produces two 'coherent' photon signals that traverse large distances on separate fiber optic paths (8.1 and 9.3 km). The 'transit lifetimes' of the signals are functions of the velocity of the signals in the medium and their distances to the FDs in the Bellevue/Bernex CEN. Signal mapping of the FD/FC detection events in the CEN via a 'clocked' memory system linking the two 'node' leads to causal ordering. The entangled photons remained 'correlated' even though separated by 10.9 kilometers, upon their detection 'decohere' with the production of 'classical' information (i.e. the emission of 'signals' or the creation of 'states' in memories) upon measurement.

The existence of spatially extended quantum states in networks depends on the entanglement of the states of the components. Entanglement allows CEs to emerge and decay. The lifetimes of these states is controlled by environmentally induced decoherence. *Decoherence lifetimes* can be extended by 'self-measurement' or 'feedback' with the CE or environment. This allows for the existence of macroscopic quantum states of networks. The lifetimes can also be shortened by decohering signals causing 'feedforward' of the evolution of the system. If the interaction extends the lifetime of the state then entropy is minimized. If the lifetime is shortened then entropy is maximized. Information loss is a measure of the entropy of the system. It is lost via emitted signals to the environment.

Quantum entanglement of the states of many components of a network can then 'define' the collective excitation as the *resultant state* of the coupled interactions of all the nodes. CEs may also interact with each other. This may lead to entanglement of various states of a plateau of complexity creating a higher order CE. Nesting of sets of entangled states within causal networks can lead to an entangled state composed of entangled states. This may provide a basis for the existence of spatially extended complex higher order CEN quantum states over 'classically' separated nodes of a causal network.

The emergence of classical systems as collective effects of networks of quantum systems through a process of collective excitation state signal production and the 'decoherence' of quantum superpositions of states into 'classical' signals and systems calls for a description in which the lifetimes of unstable states of systems of all sizes 'correspond' in a logical way to the reconfiguration processes of their subsystems. For an 'open' system (e.g. an atoms electron in an excited state) the decoherence can be induced its coupling to its 'environment' (e.g. the 'vacuum' plus QED 'self-interaction'). The definition of the systems' environment depend of the specific property

or state of the system is interacting with the 'external' space in which it is embedded. For example the 'vacuum' may not be the relevant environment for the chemically driven metabolic activities of a cell although it 'exists' between the chemicals. However it is an essential 'environment' for virtual particle production and decay and the 'Casimir' forces of attraction between two flat parallel plates in it [29]. The initial state of the universe can be considered to be self-contained 'closed' system with no 'external' environment. It can however have an 'environment' composed of primordial density perturbations from CE 'phonons'. The phonon states may have been frozen out as hierarchical clusters of matter or 'caused' the decoherence of the initial state of the Universe driving inflation and the Big Bang.

If we look at the boundary conditions (e.g. gravitation) defining a closed *system* of mass-energy as it's *apparatus* then the unstable initial state of the universe is due to the *collective excitation 'environment'* of the system plus its boundary conditions. The excited state may be the result of 'constructive' interference of some or all of the possible reconfiguration states.

In collective modes of  $n$ -body nuclei [20], the CE 'environment' is the phonon field with a characteristic multi-phonon spectrum. The 'boundary condition' acting as an apparatus 'measuring' the nuclear configuration state of the system is the 'surface tension' due to the binding energy of the strong interaction between nucleons in the nucleus. The phonon resonances of the nucleus and its 'surface' represent a prototypical collective excitation that emerges at a plateaus of complexity for this CE. 'Giant resonance' collective excitations of nuclei emerge from the coherent states of the nucleons. The resulting decay of the resonance by decoherence of the CE is caused by its coupling to the non-coherent modes of motion for the nucleus resulting in the 'damping' of the collective motion. If the CE has enough energy to exceed the stationary state equilibrium energy, then the system 'decays' irreversibly into a new configuration.

The interaction of the CE with the internal configuration states of the system is a time independent '*self-measurement*' [27] which causes the system to 'decay' or decohere irreversibly. The CE acts as the 'environment' coupling the present configuration to all the possible 'future' reconfiguration states. In the case of the universe the difference between the non-stationary 'closed' initial state and the 'open' expanding system is the creation of the 'vacuum' as a decay product. The **expansion** the universe is now a *collective excitation* of the mass-energy plus gravitation system.

The CEs of systems may act as measurements on the internal states by the surface environment. This surface represents a plateau of complexity for these systems. These plateaus have collective behaviors including

irreversible transitions to new configurations of matter and energy in expanding space. One can artificially ascribe scaled arrows of time for these plateaus. These system dependent arrows are derived from the quantum arrow of time. They '*correspond*' to the quantum arrow through the collective excitations and behaviors of the networks of clocks and signals throughout the hierarchical clusters of information processing subsystems.

## 5 Signals

A signal is any 'system' that conveys information from one system (e.g. FC) to another (e.g. FD). The creation of a detector state from a signal state is the end process of information transfer originating in a spatially distinct FC. The state information transfer causes the reconfiguration of the detection system resulting in an unstable state of 'excess' information.

The signal path length,  $d$ , combined with this 'derived' velocity,  $v$ , (at this point assumed constant) can be used to find the '*lifetime*' of the signal from its creation by an FC to its annihilation by a FD. This 'lifetime' is the classical transit 'time' of the signal given by the macroscopic or classical relation:

$$\tau_{signal} = \frac{d}{v} \quad (3)$$

For any 'classical' arbitrary trajectory of a signal in space with a non-constant velocity function of 3-space position  $\vec{\mathbf{r}}$ , the classical velocity function  $\vec{\mathbf{V}}(\vec{\mathbf{r}})$ , and the differential signal direction,  $d\vec{\mathbf{r}}$ , are dependent on a fundamental interaction of the signal with the medium/environment through which it passes. The net 'lifetime' of the signal is found by integrating over the path from source clock position,  $C(\vec{\mathbf{r}}_0)$ , to detector position,  $D(\vec{\mathbf{r}}_l)$ . The 'classical' lifetime of the signal is then:

$$\tau_{signal} = \int_{C(\vec{\mathbf{r}}_0)}^{D(\vec{\mathbf{r}}_l)} \left( \vec{\mathbf{V}}(\vec{\mathbf{r}}) \right)^{-1} \cdot d\vec{\mathbf{r}} \quad (4)$$

The 'classical' and 'quantum' lifetimes of signals overlap for cases. The first case is when the signal trajectory path length is of the order of collective excitation modes of the system and is bound to the system. This means that the 'signal' does not propagate 'freely' as in the case of photons created by decay processes inside a star.

It becomes a 'classical signal' if it propagates 'freely' in space. The decoupled photon escaping the surface of a star (subject to gravitational redshift effects) carries state information about its 'last' source in a networks of sources. A photon can be a quantum or classical signal depending on the environment in which it propagates. This is really an artificial separation that is intended to illustrate the subtle nature of the correspondence principle connecting the quantum description of signals with the 'classical' electromagnetic wave formalism.

The lifetime of a signal from emission (excited state), propagation (decoherence or decay lifetime), to its detection ('ground state') can be viewed as the decay of a single collective excitation of a s-FC system composed of original source FC, the vacuum or other signal medium, and the FD. The FC and FD at either ends of the signal trajectory 'bound' the s-FC. The 'quantum lifetime' of the 'signal' or its *equivalent* s-FC system is:

$$\tau_{C \rightarrow D} = \frac{\hbar}{\Gamma_{C,D}} = \tau_{signal} \quad (5)$$

where  $\Gamma_{C,D}$  is the decay reconfiguration information in the form of the natural width of the resonance (excitation state).

## 6 Feynman Clocks (FCs)

Feynman diagrams are the source of Feynman clocks created by transforming the 'time' component (dimension) of the incoming and outgoing signals into the state information content of those signals. The interaction (collision or scattering) of the incoming signals creates a Feynman clock for the case in which there was no pre-existing matter in that volume of space. For the case of a 'target' interacting with incoming signals, the system composed of absorbed or scattered signals and the target form a Feynman detector in that volume of space. The target 'detects' the signals in the process of interaction with them in which new states of the composite system are created. If this system is unstable, then the Feynman detector mode of the target has become a Feynman clock. Generally the incoming particles create a clock where there was no clock before. FCs may be 'open' or 'closed' in relation to the incoming and outgoing signal trajectories.

For incoming signals whose total momentum is;

$$\mathbf{p}_0 = \sum_{i=1}^m \mathbf{p}_i \quad (6)$$

resulting in the creation of outgoing signals whose total momentum is;

$$\mathbf{q}_0 = \sum_{j=1}^n \mathbf{q}_j \quad (7)$$

a 'transient' clock system is created through reconfigurations of the matter and energy in the signals via the strong, electromagnetic, weak, and gravitational fundamental interactions (indexed by  $I = s, em, w, g$  respectively). The **net** Feynman clock 'lifetime' from the system state created by the interacting incoming signals (FD mode) through the 'decay' process (internal 'decoherence' mode collective excitation state decay) to the state in which the outgoing decoupled signals are emitted (FC mode) is given by;

$$\tau_{FC_{net}} = \frac{\hbar}{\Gamma_{FC_{net}}} = \frac{\hbar}{\int \dots \int_{q_n \dots q_1} \left[ \frac{V^{n+1}}{(2\pi)^{3n+4}} \mathbf{P} \cdot |\mathbf{M}_I|^2 \delta_4(\mathbf{p}_0 - \mathbf{q}_0) \right] dq_1 dq_2 \dots dq_n} \quad (8)$$

$$= \frac{\hbar}{\int \dots \int_{q_n \dots q_1} \left[ \frac{V^{n+1}}{(2\pi)^{3n+4}} \mathbf{P} \cdot |\mathbf{M}_I|^2 \delta_4 \left( \sum_{i=1}^m \mathbf{p}_i - \sum_{j=1}^n \mathbf{q}_j \right) \right] dq_1 dq_2 \dots dq_n} \quad (9)$$

If there is no reconfiguration of the incoming signals and target (if any) in this region of space, then a clock has not been 'created' and the reduced fundamental interaction matrix element  $M_I$  (Note: equal to the  $S$ -matrix (the 'scattering' matrix) except for the  $\delta$ -function for overall energy-momentum conservation) [28] is zero:

$$\mathbf{M}_I = 0 \quad (10)$$

The above equations for the Feynman diagram method for FD/FC 'lifetimes' represent the creation of 'lifetime' information from a scattering process that in general is very difficult to compute for complex systems. The idea here is that a 'collective excitation system' is created by the incoming signals leading to an irreversible decay with the production of outgoing signals. The transformation of the incoming signals by collisional 'processing' in a target 'gate' creates new information in the form of the novel emergent signal states.

## 7 Collective Excitation Networks (CENs)

Collective behaviors of systems composed of discrete but connected components need to be characterized in order to understand how 'arrows of time' emerge in complex systems. The concept of 'collective excitations' in the many-body problem [22] and in phonon behavior in solids [24], [25] provides the basis for modeling reconfigurations of states in causal networks that represent 'plateaus of complexity' such as the lifetimes of phase in cell reproduction. When a set of subsystems in a complex system are 'wired' together in a network, they can act as a coherent superposition of states capable of supporting new excited states of that network (possibly within other networks). These collective states have finite lifetimes and decay with the production of 'signals' (e.g. phonons, solitons, plasmons, 'sound waves', etc.).

The first level of complexity emerges when sets of *coupled* Feynman clocks act collectively as a single system with new system energy eigenstates (e.g. molecular spectra) whose unstable excitation modes decay with finite lifetimes. This system is a **Collective Excitation Network** or **CEN**. These CENs can support new *collective excitation states and signals*. They can also act as 'gates', memories, or registers creating and processing signals (information) when embedded in larger networks. This process of 'nesting' of subsystems with collective excitation states provides a means for deriving various hierarchical 'arrows of time' connected with plateaus of complexity.

A CEN composed of coupled FCs. Below is the representation of the CEN node for mapping information flow in causal networks. The next level of temporal complexity arises when sets of individual Feynman clocks and CENs interact to form CEN 'circuits' with *multiple inputs and outputs* as in the case of generalizing a simple quantum clock into a Feynman clock. These 'integrated' circuits or arrays act as a single unit with collective states unique to the subsystem as a whole.

The lifetime of a CEN is given by:

$$\tau_{CEN} = \frac{\hbar}{\Gamma_{CEN}} \quad (11)$$

## 8 Sequential Excitation Networks (SENs)

SENs are sets of FCs and CENs processing signals in series.

The 'lifetime' of a SEN is the signal processing 'lifetime' marked by an incoming input 'signal',  $S_{IN}$ , to creation of an output signal,  $S_{out}$  for a set

of FCs, CENs, sub-SENs and the signals between them is the sum of the lifetimes along the computational path from input to output of each of the 'gates' and signals. The SEN 'lifetime' for this process is given by:

$$\tau_{nsum} \equiv \sum_j (\tau_{FC_j} + \tau_{S_j}) \quad (12)$$

where the CENs and sub-SENs are treated as FCs (note: the FC 'lifetime',  $\tau_{FC_j}$ , as used here is a sum of the FD lifetime, decoherence lifetime if any, and the quantum (Feynman) clock decay lifetime for that 'node').

**Feedback, feedforward and cyclical flow of signals (information)** is also possible in the SEN. This provides a mechanism for the resetting of unstable configurations necessary for quantum computational algorithms. It also provides for adaptive behavior in relatively closed systems like cells. These 'control' mechanisms can be realized by defining signal trajectories or 'circuits' connecting various nodes into hybrid linear and cyclical causal networks. All of the combinatorial possibilities for 'connecting' systems and subsystems together by signal loops provide a means for modelling complex self-adjusting or adaptive behaviors in which the continual transformations of the local states or their relative network configurations of FD/FC, CEN, and SEN nodes produce different computational 'lifetimes' for the information 'currents' propagating through them.

When systems of FCs, CENs, and their signals act as distinct nodes and arcs in a causally ordered network, the transfer of configuration information through the system can be 'sequential' from a set of inputs to a set of outputs. If the entire '*heterogenous*' system acts like a 'black box' clock then details of the internal processes are embedded in a **Sequential Excitation Network** or **SEN** of FCs and CENs.

## 9 Plateaus of Complexity (POCs)

As we have seen above collective excitations are the markers for new levels of complexity in hierarchically connected systems. Solitons represent 'classical' wave packet signals in macroscopic scale systems. Their origins are found in the plateaus of complexity of the subsystems from which they are composed. Since CEs are the result of the superposition of *quantum states resulting in another quantum state*, classical states emerge as the result of the interaction of this system with an *environment*. Plateaus of complexity are the interface between the quantum properties of the system and its environment. This is



how quantum systems in CENs and SENs can create 'classical' signals and behaviors as a result of the environmental measurement by an observing system in which it is embedded. The environmental component makes the quantum system 'open' to classical signal production. If the environment is the boundary condition on the quantum system it may be 'closed' but still act like an open system which can decohere (e.g. decay of FC mode of the initial state of the universe in Big Bang scenarios).

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## 10 Signal Mapping

Signal mapping is the process by which signals carrying state information are detected and their 'information content' (induced state in detector) put into ordered sets with respect to a standard or internal clock. This involves creating states in a 'memory' so that their causal relation to other events can be 'labeled' and interpreted. 'Time' emerges as the functional value of the energy eigenstates in the detectors as information 'bits' assigned to a detected signal from an 'event' (FC created signal) in 3-space (possibly  $n$ -space at the Planck scale for higher dimensional quantum modes of 'strings' etc.).

### 10.1 Temporal 'Unification' of the Fundamental Interactions

For a FC (or CEN in each of the following) reconfigured by the strong interaction we have a decay lifetime  $\tau_U$  :

$$\tau_U = \alpha\tau_{strong} = \frac{\hbar}{\Gamma_{strong}} \quad (13)$$

For a FC system driven by the weak interaction (or 'electroweak') we have:

$$\tau_U = \beta\tau_{weak} = \frac{\hbar}{\Gamma_{weak}} \quad (14)$$

For a FC system driven by the electromagnetic interaction (QED photon/electron processes) we have:

$$\tau_U = \delta\tau_{em} = \frac{\hbar}{\Gamma_{em}} \quad (15)$$

and for a gravitational FC system we have:

$$\tau_U = \epsilon\tau_{grav} = \frac{\hbar}{\Gamma_{grav}} \quad (16)$$

where the lifetimes are related by real scalar constants  $\alpha$ ,  $\beta$ ,  $\delta$ , and  $\epsilon$ . The unified 'lifetime',  $\tau_U$  is then:

$$\tau_U = \alpha\tau_{strong} = \beta\tau_{weak} = \delta\tau_{em} = \epsilon\tau_{grav} \quad (17)$$

These four prototypical systems are reconfigured by different forces but their signals provide a rather obvious and perhaps trivial way of establishing an ad hoc unification of the fundamental interactions of matter in an *information space* [17]. The key to this type of unification is recognizing the dimensional equivalence of the 'lifetimes' and therefore the source 'information' common to all the fundamental interactions and that the systems can act like 'clocks' producing signals that carry information to detectors.

Signals generated in the decay processes above carry state information to detection systems where the signal generating events can be 'measured' with respect to each other as functions of 'arrival times', signal spectra energy distributions, and spatial directions. This process of signal mapping by an observing system creates the 'times' in the ordered sets of sequential events. The ordering is with respect to an internal or external standard 'cyclical' FC system. At this point the *differences* in the order of the detected signal states can be used to create the 'difference times' or secondary 'event times' used in the 'coordinates' and time dimension of the space-time of special and general relativity.

At a subtle level it is the *information* (e.g. specific energy states associated with 'signals') flow between these systems that may ultimately provide a context for working 'backward' from collective features of systems to the unification of physical laws in the microscopic domain of particle physics. This represents a rather obvious and perhaps trivial way of viewing the unification of the fundamental interactions of matter from the information and 'lifetime' frame of reference. The key to unification may be seen in the 'lifetime' or information terms common to all these interactions. This occurs in the dynamic transfer of state 'information' flowing between the casual network 'gates' of the universe modeled as an evolving Big Bang Feynman Computer.

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